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GAS TURBINE AND JET ENGINE FUELS

PROGRESS REPORT NO. 2

NAVY BUWEP CONTRACT N600(19) - 58219

AUGUST, 1962

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PHILLIPS PETROLEUM COMPANY

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Feature No.,6045
August 24, 1962

Progress Report No. 2
Navy Contract N600(19)-58219
GAS TURBINE AND JET ENGINE FUELS

By

William L. Streets

35

S U M M A R Y

The second bimonthly period under Navy Contract N600(19)-58219 has been spent continuing the study of the effects of sulfur in jet fuels on the durability of engine "hot section" components. Efforts during this period have included: (1) Evaluation of the effects of fuel sulfur content on the loss of metal from Udimet 500, Waspalloy, Stellite 25, Hastelloy R-235, René 41 and Inconel X simulated turbine inlet guide vanes in the two-inch high-pressure research combustor under conditions producing approximately 2000F exhaust gas, (2) extended duration metal durability testing with the atmospheric pressure Phillips Microburner using Udimet 500, Waspalloy, Stellite 25 and René 41 simulated guide vanes, and (3) determination of the tensile strengths of the above superalloys before exposure in the 2-inch combustor for later comparison with tensile values after exposure to sulfurous exhaust gases.

The results obtained with the two-inch combustor during this reporting period indicate that: (1) none of the alloys tested were detrimentally affected by one per cent fuel sulfur at 2000F over a six-hour test duration; (2) Stellite 25 yielded lowest metal losses while Hastelloy R-235 yielded highest metal losses -- these extremes differed by a factor of five while the balance of the alloys were intermediate and differed by values within the repeatability limits of method and apparatus; (3) repeated catastrophic failures of René 41 test strips tentatively appear due to intergranular oxide precipitation resulting in cracking which may also have been aggravated by internal stresses caused by cold working during fabrication; (4) accumulation of additional test time is indicated as necessary in order to establish a trend for sulfur effects on the durability of these superalloys. Extended Microburner tests corroborated the need for extension of test duration in future 2-inch combustor work. Tensile strength data obtained on guide vane test strips agreed well with literature values and/or manufacturer's tensile data.

SEP 19 1962

Research Division Report 3273-62R

PHILLIPS PETROLEUM COMPANY

BARTLESVILLE, OKLAHOMA

Progress Report No. 2
Navy Contract N600(19)-58219
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I. INTRODUCTION

The second bimonthly period under Navy Contract N600(19)-58219 has been spent continuing the study of the effects of sulfur in jet fuels on the durability of engine "hot section" components. Efforts during this period have included: (1) Evaluation of the effects of fuel sulfur on the loss of metal from Udimet 500, Waspalloy, Stellite 25, Hastelloy R-235, René 41 and Inconel X simulated turbine inlet guide vanes in the two-inch, high pressure combustor under conditions producing approximately 2000F exhaust gas, (2) extended duration metal durability testing with the atmospheric pressure Phillips Microburner using Udimet 500, Waspalloy, Stellite 25 and René 41 simulated turbine inlet guide vanes, and (3) evaluation of the tensile strengths of the above superalloys before exposure in the 2-inch combustor for later comparison with tensile values after exposure to sulfurous exhaust gases.

II. TEST METHODS AND APPARATUS

A. Phillips 2-Inch Research Combustor Tests

The Phillips 2-Inch Research Combustor, illustrated in Figure 1, has been described in previous reports (1). Briefly, this is a 2-inch diameter axial flow combustor embodying the principal features of modern jet engine combustion systems. Air is supplied to this combustor from a compression and heating plant described in (1), while fuel is supplied to the swirl type nozzle by nitrogen pressurization. The design of the combustor provides for ready removal of flame tubes and guide vane test pieces for weighing and inspection.

The test conditions employed were the same as those used for previous investigations of the effect of sulfur and sea water on flame tubes and turbine inlet guide vanes which have been reported in (2), (3) and (4). Combustor pressure was held at 350 in. Hg abs., inlet air temperature at 700F and inlet reference velocity at 100 fps, providing a severity level which is realistic for high compression ratio turbojets operating at relatively low altitudes. The tests conducted during this reporting period have been carried out entirely at a fuel/air ratio of 0.020 (resulting in an exhaust gas temperature of approximately 2000F) in order to provide temperature conditions realistic in terms of the more advanced engine designs.

No change was made to the combustor for the investigation of guide vane metal loss. The only change in apparatus was simply to add a six-inch spool piece downstream from the combustor and to cut a suitable holder cavity into its mating flange for the test pieces, placing these pieces in a position comparable to blading in an actual engine. Earlier work reported in (4) was carried on using a cartwheel-shaped specimen to simulate guide vanes. Owing to the difficulties encountered in fabricating this shape from the relatively hard-to-work superalloys, a change in specimen configuration has been adopted during this reporting period. The new specimens are simply 1/2" x 2 3/8" strips cut from 16 gauge sheet. Two of these strips are placed in the exhaust gas stream as shown in Figure 2.

Weight losses from the blading test pieces were measured following each of three consecutive two-hour test periods. During this reporting period vane pieces fabricated from Udimet 500, Waspalloy, Stellite 25, Hastelloy R-235, René 41 and Inconel X have been tested. The compositions of these alloys are shown in Table I. Stellite 25 was substituted for Stellite 31, which is unavailable in the sheet form necessary for fabrication of test pieces.

Stellite 25 is, however, comparable in composition to Stellite 31. Inconel X was included primarily as a high nickel alloy for reference purposes. The balance of the alloys are either in current use in operational engines as blading materials or proposed for such use.

Since previous investigations (3) had shown sulfur compound type to be unimportant as compared to gross sulfur content, it was decided to continue using ditertiary butyl disulfide as the sulfur contaminant since it is inexpensive and available at adequate purity. As in previous tests this compound was employed at sufficient concentration to realize a fuel sulfur content of 1.0 per cent.

The base fuel used in all the tests reported herein, as in previous tests, was a JP-5 type isoparaffinic alkylate containing less than 0.005 per cent sulfur.

B. Phillips Microburner Guide Vane Metal Loss Tests

Further testing has been carried on during this reporting period using the Phillips Microburner which has been adapted for measuring metal losses from simulated turbine inlet guide vanes. This apparatus has been described in detail in (5). Briefly, this apparatus is a 1.25-inch diameter atmospheric pressure tangential flow bench scale combustor. It is illustrated schematically in Figure 3. The exhaust system has been modified to allow placement of test materials in the exhaust stream. Simplified test pieces consisting of four 1/16" x 1/4" x 1 1/2" strips have been used. The position of these strips in the exhaust stream is illustrated in Figure 4. The holder containing the strips is clamped between the flanges shown in Figure 3. Exhaust gas temperature measurements are made by means of four equal area center thermocouples placed just upstream from the strips. The conditions of operation chosen for these tests were 500F inlet air temperature, 25 fps

inlet reference velocity and 0.055 fuel/air ratio. This lean fuel/air ratio was chosen to provide a moderate amount of excess air (this burner uses no secondary air).

It will be recalled from (4) that some difficulty caused by lack of repeatability in descaling the Microburner test strips brought about several false starts. This problem was traced to excessive brushing of the edges of these rather small specimens. It is believed that this problem has been satisfactorily solved during this reporting period. Determination of weight losses from the test strips are made in the same way as in the 2-inch combustor tests. Weighings have been made at two-hour intervals for a total test time of 20 hours. The data are reported as combined weight loss from all four test strips.

The Microburner data are intended to supplement the 2-inch combustor data and eventually provide a means for more rapid evaluation of the effect of fuel and air contaminants on a wide variety of practical turbine blading alloys.

C. Tensile Testing of Unexposed Superalloys

Determinations of the stress-strain characteristics of Udimet 500, Waspalloy, Stellite 25, Inconel X, Hastelloy R-235 and René 41 before exposure in the combustor have been made during this reporting period. These data on original strength properties will be used to determine whether or not a loss of strength occurs as a result of exposure to oxygen-rich sulfurous and/or sea salt laden exhaust gases by comparison with tensile strengths of the exposed specimens to be obtained following completion of the combustor testing. Since there have been indications (as explained later herein) that longer duration 2-inch combustor tests would be advisable, the tensile testing of exposed guide vane specimens has been postponed in favor of carrying the existing six-hour exposure specimens on to longer durations. This avoids restarting the combustor tests.

Although strength data on these alloys are available in the literature it was deemed advisable to obtain tensile strengths on the exact heats used in the combustor tests. Additionally, it has been noted from the literature values that a significant difference sometimes occurs between strengths obtained on specimens prepared from bar stock and those prepared from sheet stock. Heat treatments, which were in general unknown for the samples tested, can also bring about large changes in strength of these alloys. The decision was therefore made to prepare tensile test specimens from the strips as used in the guide vane metal loss tests. The configuration of these tensile specimens is shown in Figure 5. They are prepared by simply milling the reduced section from the 1/2" x 2 3/8" x 16 gauge guide vane specimens. Tensile test specimens will be prepared from the exposed alloys in exactly the same way.

The tensile data reported herein were obtained directly as elongation versus load on an x-y plotter using an Instron Model TTC testing machine operated at a crosshead travel of 0.1 inch per minute. Gage length was one inch. The data reported herein have been reduced to unit stress versus per cent strain plots.

III. DISCUSSION OF EXPERIMENTAL RESULTS

A. Two-Inch Combustor Turbine Guide Vane Metal Loss Tests

The data obtained during this reporting period on metal loss from Udimet 500, Waspalloy, Stellite 25, Inconel X, Hastelloy R-235 and René 41 simulated turbine inlet guide vanes in the Phillips 2-Inch Research Combustor are shown in Table II and Figure 6. These tests were run at a nominal exhaust gas temperature of 2000F, which is representative of maximum turbine inlet temperatures in advanced design engines.

It will be observed from Figure 6 that, with the exception of René 41, 1.0 per cent sulfur had either no effect or an apparent beneficial

effect on the durability of this group of superalloys. A simple analysis of variance (two variables of classification fuels and metals -- single observation) was performed on these data. This analysis resulted in an acceptance of the null hypothesis, that is, that there is no difference (95% confidence) among the means of the two fuels (base and base plus 1 per cent S). In other words, these tests suggest that 1.0 per cent fuel sulfur is neither beneficial nor detrimental -- at least for a test duration of six hours. However, analysis of the variance of these data in terms of alloy effects resulted in a rejection of the null hypothesis, that is, a significant difference among means of the different metals is indicated. The results of the analysis of variance are shown in Appendix I.

Although a numerical correlation of the above described data obtained with the strip type specimen configuration with those obtained with the cartwheel configuration reported in (4) does not appear particularly favorable, there is qualitative agreement as to effects of sulfur in the fuel. For the four alloys (Udimet 500, Waspalloy, Stellite 25 and Inconel X) which have been tested in both configurations sulfur has shown no detrimental effect in either case for a test duration of six hours.

Considering the results shown in Figure 6 simply in terms of the relative durability of the several alloys, it will be noted that the extremes are Stellite 25 (lowest loss) and Hastelloy R-235 (highest loss). These extremes differ by a factor of about five while the balance of the alloys lie approximately intermediate and differ from each other only by values believed to lie within the repeatability of the test method and apparatus.

It is of interest that in the course of running the tests on René 41 with the base fuel considerable difficulty was encountered with repeated catastrophic failures of the test strips. Four consecutive starts resulted in complete failure of one of the two test strips within the first two-hour

period. Although tests with and without sulfur in the fuel were eventually completed and showed no outstandingly high metal losses, it was considered desirable to submit a pair of the fractured strips to metallurgical examination. Although the analysis of these failures is incomplete there is some suggestion that intergranular precipitation of oxides resulted in cracking of the strips. This effect may also have been aggravated by internal stresses present at the edges of the test strips as a result of cold working arising from the shearing operation used to prepare the strips. There is also some evidence that propagation of cracks occurred from the edges inward. This problem has also been referred to the manufacturer, Haynes Stellite Company, for an expression of their opinion of the probable cause of failure.

B. Phillips Microburner Turbine Guide Vane Metal Loss Tests

The results of extended duration tests on Udimet 500, Waspalloy, Stellite 25 and René 41 conducted with the Phillips Microburner are shown in Table III. These data show some tendency toward increased corrosion in the presence of 1.0 per cent fuel sulfur for test durations exceeding 14 hours. The most notable feature of these Microburner data, however, is the indication of pronounced detrimental effect of sulfur on Stellite 25. This was in evidence from the beginning of the test. It will be recalled that Stellite 25 showed little or no sulfur sensitivity in the 2-inch combustor tests and was, in fact, the best performing alloy (on a metal loss basis) of the group tested. It is believed, in light of the repeatedly low metal losses obtained with ST-25 in the 2-inch combustor, that the 1 per cent sulfur test on ST-25 in the Microburner is subject to doubt. It is possible that another material might have been accidentally substituted in this test. Otherwise, these data correlate fairly well for test durations of six hours in both cases, as shown in Figure 7.

Of additional interest, with respect to testing in the 2-inch combustor, is the indication from these Microburner data that test durations longer than 14 hours are necessary in order to demonstrate sensitivity or lack of sensitivity, to the presence of sulfur in the fuel. It is believed that these Microburner data serve to point up the need for longer test durations with the 2-inch combustor to properly evaluate these high temperature alloys. In this respect it appears that the Microburner work has served an important purpose. However, due to budgetary and time considerations it has been decided to discontinue testing with the Microburner in order to allow extended duration testing in the more realistic 2-inch combustor.

C. Tensile Testing of Unexposed Superalloys

The results of tensile tests conducted on new or unexposed samples of the several superalloys involved in the combustor test program are shown in Figures 8, 9, 10, 11, 12 and 13. These results are compared with the manufacturer's data on the specific "heat" used (where available) or with literature values in the following table:

Alloy	Tensile Strength @ 70F, psi As Determined on Guide Vane Strips(1)	Tensile Strength @ 70F, psi From Manufacturer or Literature
Udimet 500	156,380	—
Waspalloy	120,650	118,000(4)
Stellite 25	146,750	146,000(3)
Inconel X	106,400	100,000-140,000 (Annealed Sheet)(2
Hastelloy R-235	130,300	122,050(4)
René 41	136,000	128,700(4)

(1) Average of two tests.

(2) Alloy Digest, March 1953.

(3) Materials in Design Engineering, October 1961.

(4) Manufacturers data on specific sample tested.

As will be noted from the above, agreement is good between data obtained on the guide vane strips and literature or manufacturer's values, indicating that the more-or-less non-standard (but necessary) tensile specimen configuration used has not unduly influenced the tensile strength values obtained. As will be noted from Figures 8-13 the elongations were quite large with this shape specimen, however. At any rate, these data appear valid and testing of the exposed (to combustion products) guide vane specimens will begin as soon as combustor testing is completed. It is hoped these data will serve to show possible effects of fuel sulfur and/or ingested sea water on turbine blading durability from the standpoint of changes in mechanical properties. These data will also supplement the photomicrographs to be obtained before and after exposure in the combustor.

IV. CONCLUSIONS

Two-inch combustor data obtained during the present reporting period on the effects of sulfur on simulated turbine inlet guide vanes suggest the following conclusions:

1. Over a test duration of six hours Udimet 500, Waspalloy, Stellite 25, Inconel X, Hastelloy R-235 and René 41 simulated guide vanes were unaffected on a metal loss basis by the presence of 1.0 per cent fuel sulfur under conditions producing nominal 2000F exhaust gas.
2. Consideration of the metal loss data in terms of relative durability of the superalloys tested shows that the extremes are Stellite 25 (lowest loss) and Hastelloy R-235 (highest loss); these extremes differ by a factor of about five while the balance of the alloys are roughly intermediate and differ by values believed to lie within the repeatability limits of the method and apparatus.

3. Repeated catastrophic failures of René 41 test specimens tentatively appear due to intergranular precipitation of oxides resulting in cracking; this effect may have been aggravated by internal stresses arising from cold working of specimen edges during fabrication.

4. Accumulation of additional test time is indicated as desirable and/or necessary in order to establish a trend for sulfur effects on the durability of these superalloys.

Additional metal durability testing conducted with the modified Phillips Microburner apparatus has indicated the following:

1. Extended duration tests on Udimet 500, Waspalloy, Stellite 25 and René 41 guide vane specimens have shown some tendency toward increased corrosion in the presence of 1 per cent fuel sulfur when test durations exceed 14 hours.

2. Correlation of Microburner and 2-inch combustor metal loss data appear encouraging for equivalent test durations (6 hours).

3. The Microburner data corroborate the need for extension of test duration in future 2-inch combustor work; due to budgetary and time considerations it has been decided to discontinue Microburner testing in order to allow more extensive testing in the Phillips 2-Inch Combustor which more nearly simulates actual operational conditions.

Tensile testing of new or unexposed samples of the several superalloys involved in this test program has shown the following:

1. Tensile strength values obtained on guide vane test strips agree well with literature values and/or manufacturer's tensile data.

2. The tensile test specimen configuration employed (Figure 5) did not unduly influence tensile strength results although elongations were quite large with this shape.

V. OUTLINE OF PROJECTED WORK

It is planned to extend the six-hour duration guide vane metal durability tests in the Phillips 2-Inch Research Combustor to longer durations during the coming reporting period in order to better establish a trend for the effect of fuel sulfur on superalloys. In addition to the superalloys tested thus far it is also planned to evaluate Udimet 700 and Hastelloy X in future work. Metallurgical and mechanical properties tests on samples of each alloy before and after exposure to sulfurous gases will begin as soon as the extended duration combustor tests are completed.

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2. Kittredge, G. D. and Streets, W. L.; "Gas Turbine and Jet Engine Fuels", Summary Report, Navy Contract NOas 58-310-d, Amendments 1 and 2, Phillips Research Division Report 2506-59R, November, 1959.

3. Kittredge, G. D., and Streets, W. L.; "Gas Turbine and Jet Engine Fuels", Summary Report, Navy Contract NOas 60-6009-c, Phillips Research Division Report 2760-61R, January, 1961.

4. Streets, William L.; "Gas Turbine and Jet Engine Fuels", Summary Report, Navy Contract NO(w) 61-0590-d, Phillips Research Division Report 3185-62R, March, 1962.

5. Streets, W. L., "Phillips Microburner - A Tool for Evaluating the Burning Quality of Jet Fuels", Phillips Research Division Report 1793-57R, May, 1957.

TABLE I

COMPOSITION OF ALLOYS USED IN TURBINE GUIDE VANE METAL LOSS TESTS

Alloy	Per Cent by Weight of Indicated Metal																
	Cr	W	Fe	C	Si	Co	Ni	Mn	Cb	Mo	P	S	Al	Ti	B	Zr	Cu
Udimet 500*	19.0	—	.36	.09	.15	18.7	51.04	<.10	—	4.35	—	.005	3.10	2.99	.003	<.01	<.10
Waspalloy*	19.5	—	.95	.053	.03	13.2	57.44	.01	—	4.41	.003	.003	1.23	3.10	.002	.06	.01
Stellite 25	20.0	15.0	3.0	.1	1.0	Bal.	10.0	1.5	—	—	—	—	—	—	—	—	—
Inconel X	15.0	—	7.0	.05	.4	—	Bal.	.5	.9	—	—	.007	.75	2.5	—	—	.05
Hastelloy R-235*	15.29	—	9.96	.15	.26	.38	63.91	.03	—	5.48	.001	.009	2.05	2.48	—	—	—
René 41*	18.33	—	1.90	.10	.16	10.69	54.37	.05	—	9.69	—	.009	1.54	3.15	.005	—	—

* Actual analyses of metal samples tested. Values shown for other alloys are typical compositions.

TABLE II

TURBINE GUIDE VANE DURABILITY TESTS IN PHILLIPS 2-INCH RESEARCH COMBUSTOR

Combustor Operating Conditions: P = 350 in. Hg abs; V = 100 f.p.s.; IAT = 700F;
F/A = .020; Exh. Temp. = 2000F Nominal

Guide Vane Alloy	Test Fuel Description	Test Time, Hr.	Accumulated Metal Loss, mg.
Inconel X	Base Fuel (350-550F Alkylate)	2	26.5
		4	79.5
		6	139.3
Inconel X	Base Fuel + 1% Sulfur	2	13.2
		4	49.8
		6	102.8
Waspalloy	Base Fuel	2	85.4
		4	118.6
		6	178.6
Waspalloy	Base Fuel + 1% Sulfur	2	47.1
		4	103.7
		6	144.0
Stellite 25	Base Fuel	2	5.5
		4	18.9
		6	52.4
Stellite 25	Base Fuel + 1% Sulfur	2	4.3
		4	30.1
		6	52.0
Hastelloy R-235	Base Fuel	2	60.1
		4	169.1
		6	234.5
Hastelloy R-235	Base Fuel + 1% Sulfur	2	26.1
		4	131.6
		6	210.1
Udimet 500	Base Fuel	2	16.4
		4	67.9
		6	174.2
Udimet 500	Base Fuel + 1% Sulfur	2	14.5
		4	52.2
		6	109.5
René 41	Base Fuel	2	37.7
		4	82.0
		6	133.3
René 41	Base Fuel + 1% Sulfur	2	44.8
		4	92.1
		6	156.9

TABLE III

PHILLIPS MICROBURNER TURBINE GUIDE VANE METAL DURABILITY TESTS

Operating Conditions: P = 1 atmos.; V = 25 fps; IAT = 500F; F/A = 0.055, Nominal Exh. Gas Temp. = 2000 ± 50F
De-Scaling Method: 6 inch Rotary Wire Brush - no edge brushing
Surface Preparation: None

		Accumulated Guide Vane Metal Loss, mg (4 Strips)									
Metal Type	Test Fuel Description	2 Hr.	4 Hr.	6 Hr.	8 Hr.	10 Hr.	12 Hr.	14 Hr.	16 Hr.	18 Hr.	20 Hr.
Udimet 500	Base Fuel	15.5	58.7	133.5	169.5	196.7	231.7	261.6	294.1	324.3	353.0
Udimet 500	Base Fuel + 1% Sulfur	17.5	36.3	66.0	98.4	131.2	158.4	208.8	253.7	313.3	379.5
Waspalloy	Base Fuel	23.3	46.5	81.2	124.7	184.5	248.9	309.8	372.1	412.8	466.3
Waspalloy	Base Fuel + 1% Sulfur	28.6	66.0	93.7	130.8	170.3	217.4	295.3	406.9	516.8	594.4
Stellite 25	Base Fuel	6.7	19.7	29.6	45.3	60.9	82.4	106.4	139.1	173.0	221.4
Stellite 25	Base Fuel + 1% Sulfur	11.2	27.2	60.0	86.3	138.4	225.1	296.8	376.4	432.2	523.1
René 41	Base Fuel	32.4	68.9	105.8	145.4	195.4	243.3	303.2	375.9	451.5	569.3

APPENDIX I

ANALYSIS OF VARIANCE (TWO VARIABLES OF CLASSIFICATION - SINGLE OBSERVATIONS) OF TWO-INCH COMBUSTOR DATA ON DURABILITY OF SUPERALLOY TURBINE GUIDE VANES

	Sum of Squares	Degrees of Freedom	Mean Square
Metal Means	30,643.90	5	6,128.78
Fuel Means	1,538.25	1	1,538.25
Residual	2,395.74	5	479.15
Total	34,577.89	11	

$$F \text{ (metal means)} = \frac{6{,}128.78}{479.15} = 12.79 \; ; \; F_{.95}\,(5,5) = 5.05$$

Reject hypothesis of no difference among means of different metals.

$$F \text{ (fuel means)} = \frac{1{,}538.25}{479.15} = 3.21 \; ; \; F_{.95}\,(1,5) = 6.61$$

Accept hypothesis of no difference among means of different fuels.

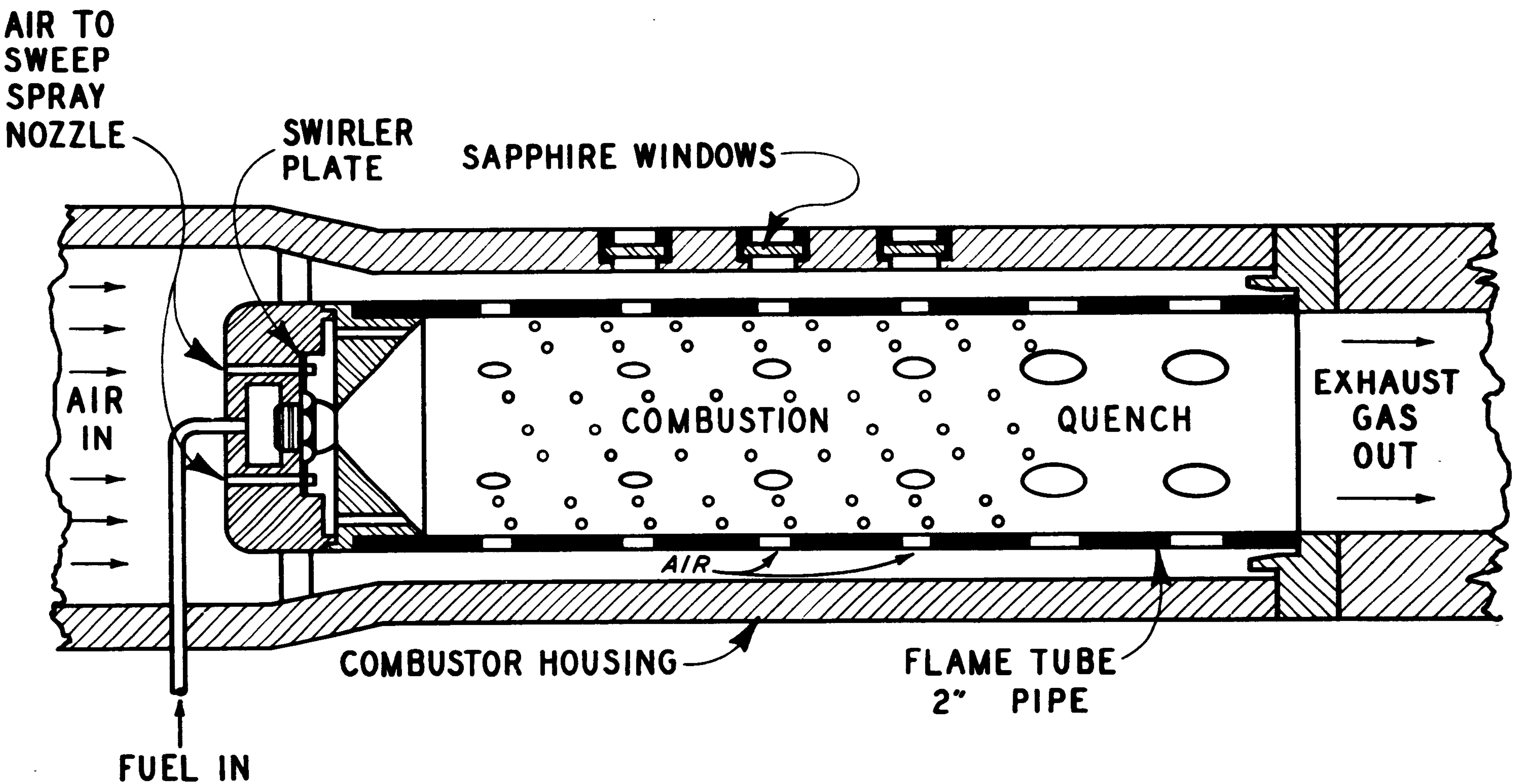

FIGURE 1

PHILLIPS LABORATORY SCALE TEST COMBUSTOR

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RESEARCH DIVISION REPORT 3273-62R

HOLDER MAT'L: 310 SS; STRIP MAT'L.: VARIOUS TURBINE BLADING ALLOYS
SCALE: 1" - 1"

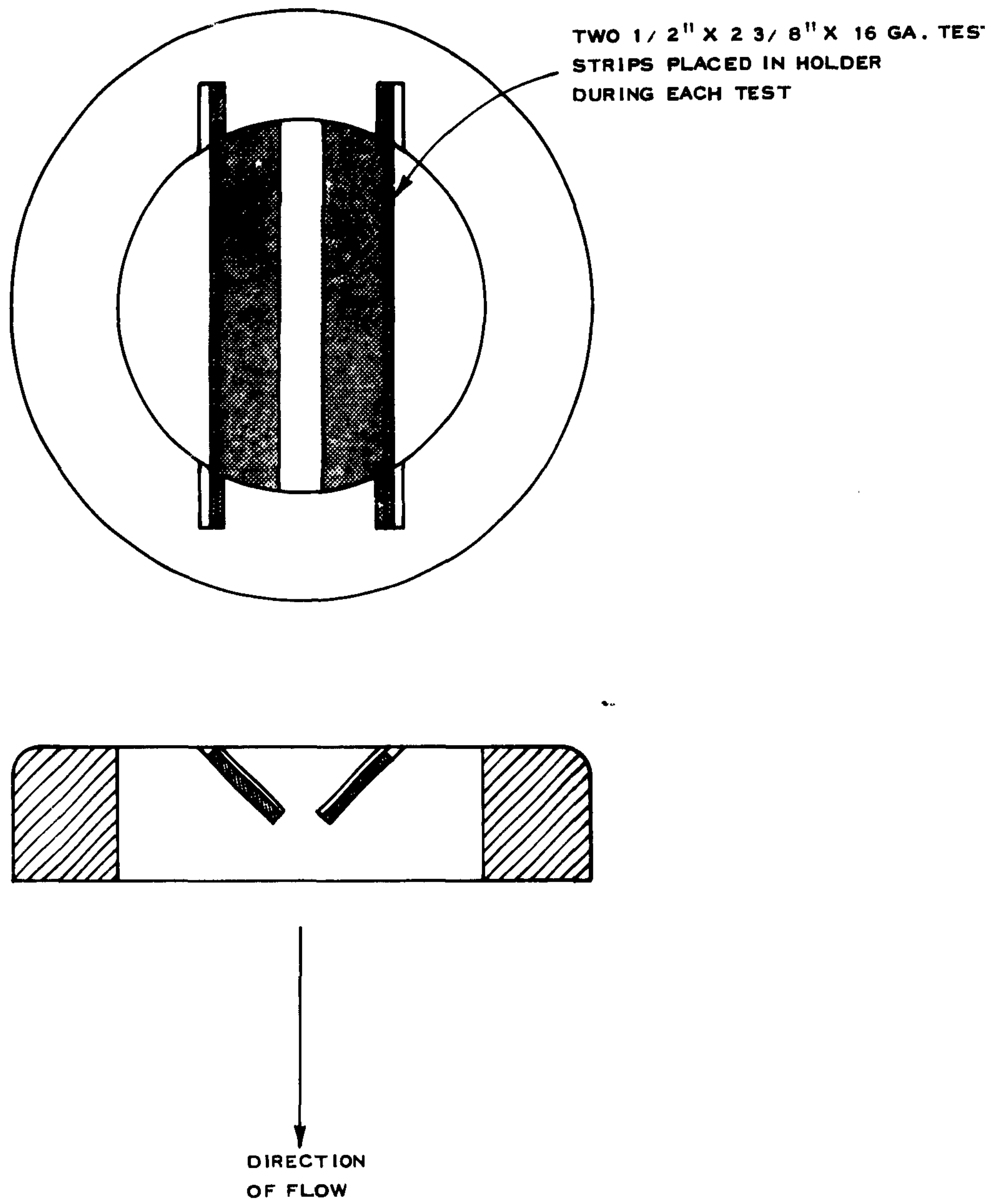

FIGURE 2
SPECIMEN HOLDER FOR PHILLIPS 2-INCH COMBUSTOR SIMULATED TURBINE INLET GUIDE VANE DURABILITY TESTS

1. AIR PRESS. REGULATOR
2. AIR PRESS. GUAGE
3. AIR ROTAMETER
4. AIR FLOW CONTROL VALVE
5. ELECTRIC AIR PREHEATER
6. BURNER BASE PRESS. GAUGE
7. PHILLIPS MICROBURNER
8. FUEL DUMP VALVE
9. FUEL FLOW CONTROL VALVE
10. FUEL ROTAMETER
11. FUEL TANK
12. N_2 BLEED VALVE
13. N_2 PRESS. GUAGE
14. N_2 PRESS. REGULATOR
15. PROPANE PILOT VALVE

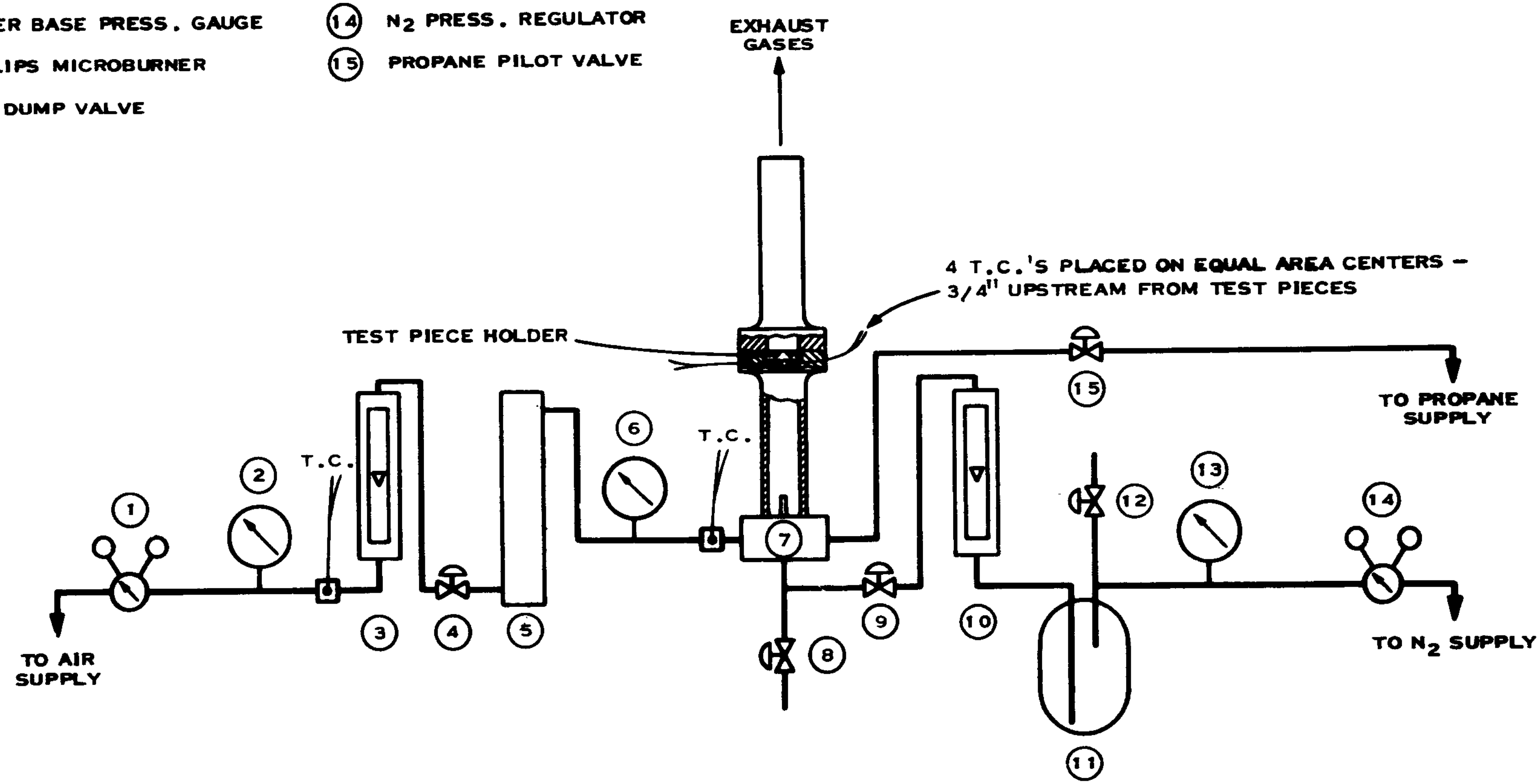

FIGURE 3
SCHEMATIC DIAGRAM OF PHILLIPS MICROBURNER ADAPTED FOR MEASUREMENT OF TURBINE GUIDE VANE METAL DURABILITY

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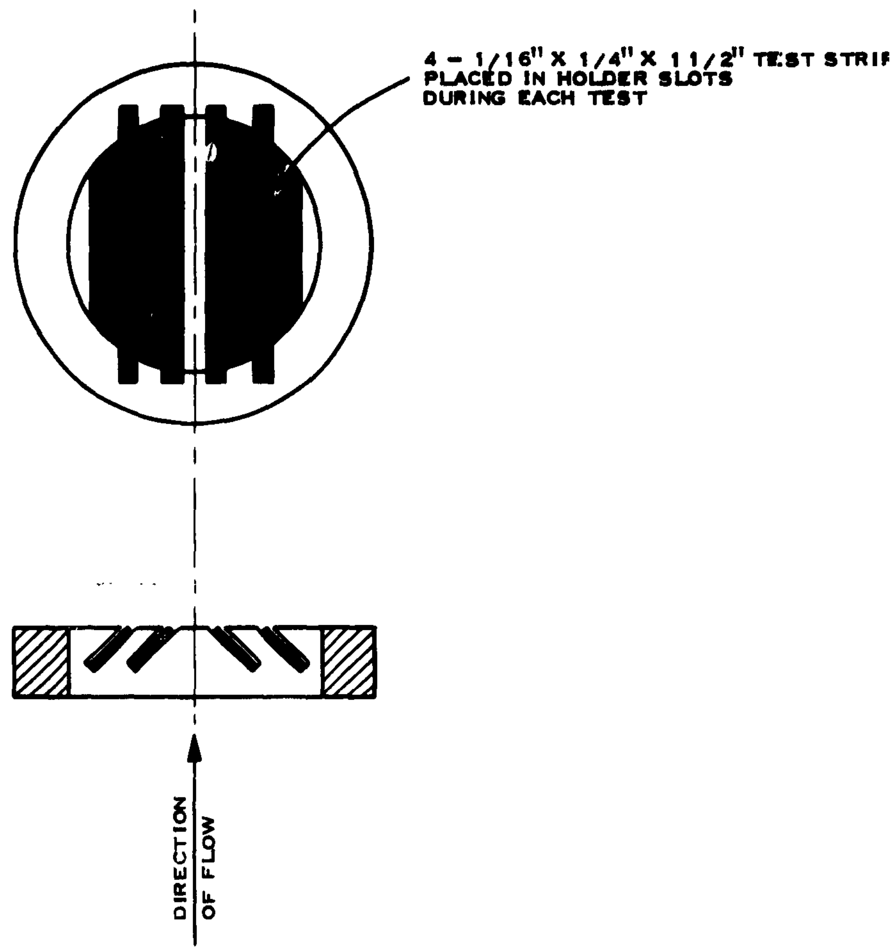
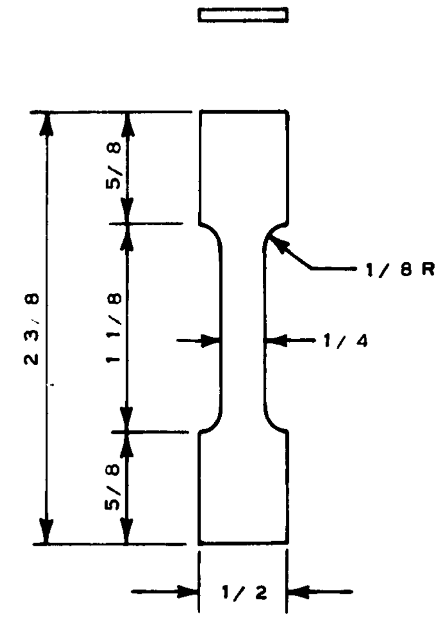


HOLDER MAT'L: 310 SS; STRIP MAT'L: VARIOUS TURBINE BLADING ALLOYS

SCALE: FULL

FIGURE 4
METAL DURABILITY SPECIMEN HOLDER FOR MICROBURNER APPARATUS



NOTE: TENSILE SPECIMENS TO BE FABRICATED FROM 1/2 X 2 3/8 X 16 GAGE NEW AND EXPOSED CORROSION TEST STRIPS FROM 2-INCH COMBUSTOR TESTS.

FIGURE 5
TENSILE TEST CONFIGURATION FOR TURBINE INLET GUIDE VANE CORROSION SPECIMENS

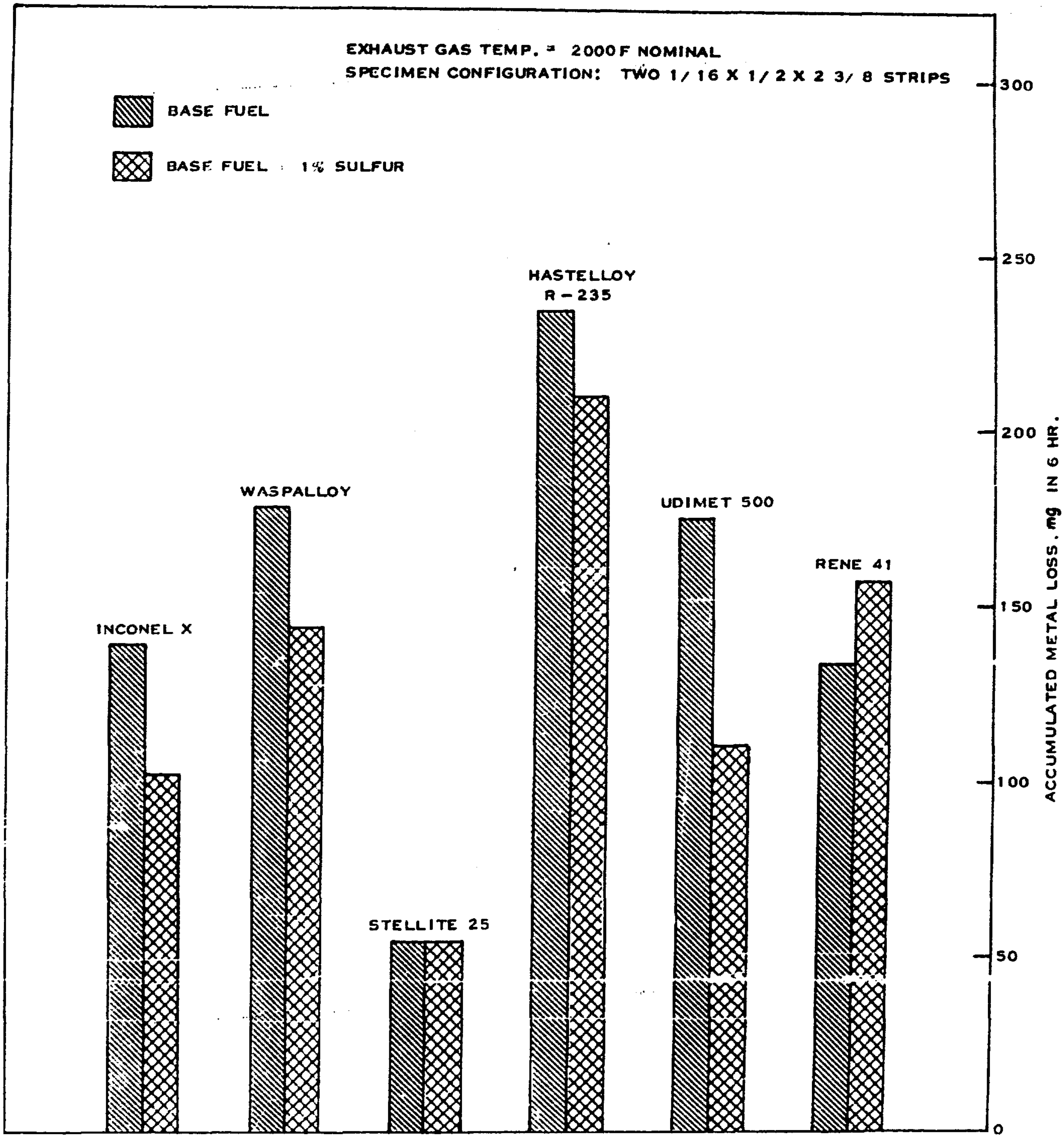


FIGURE 6
EFFECT OF FUEL SULFUR CONTAMINATION ON TURBINE INLET GUIDE VANE METAL LOSS FROM SEVERAL SUPERALLOYS IN THE PHILLIPS 2-INCH COMBUSTOR

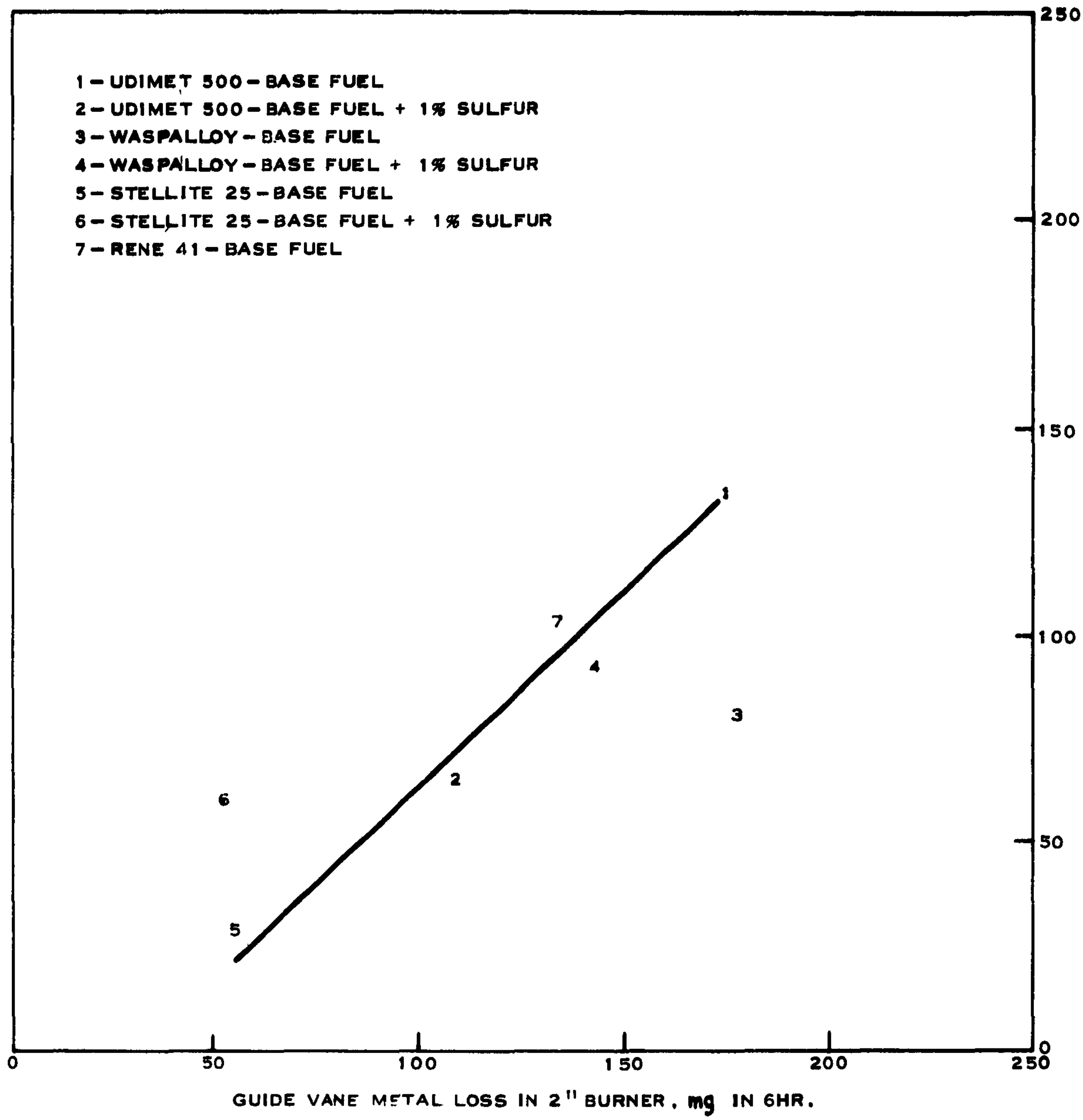


FIGURE 7
CORRELATION OF 2-INCH COMBUSTOR AND MICROBURNER GUIDE VANE METAL LOSSES FOR SIX-HOUR TEST DURATION

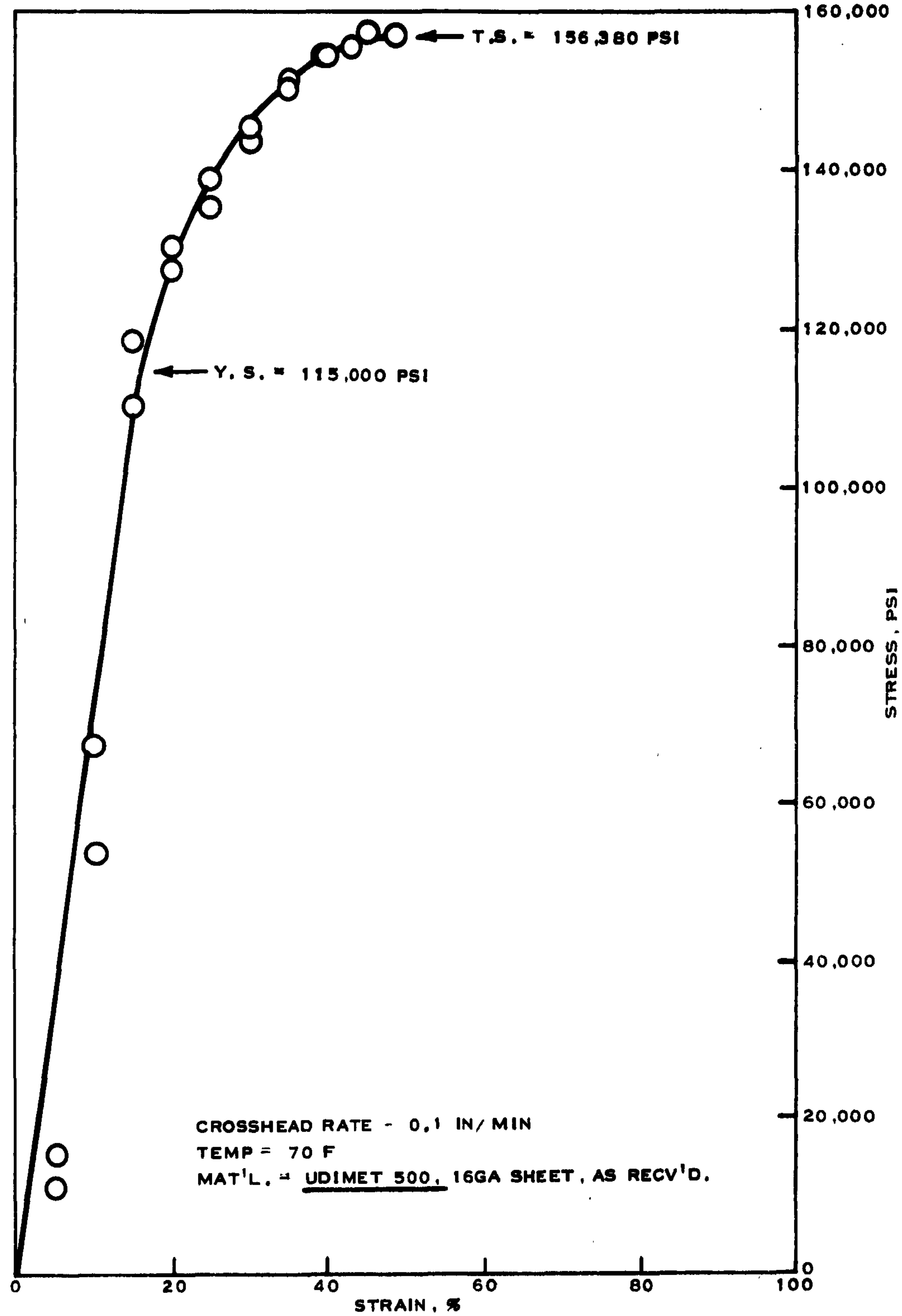


FIGURE 8
STRESS-STRAIN CURVE FOR UNEXPOSED UDIMET 500

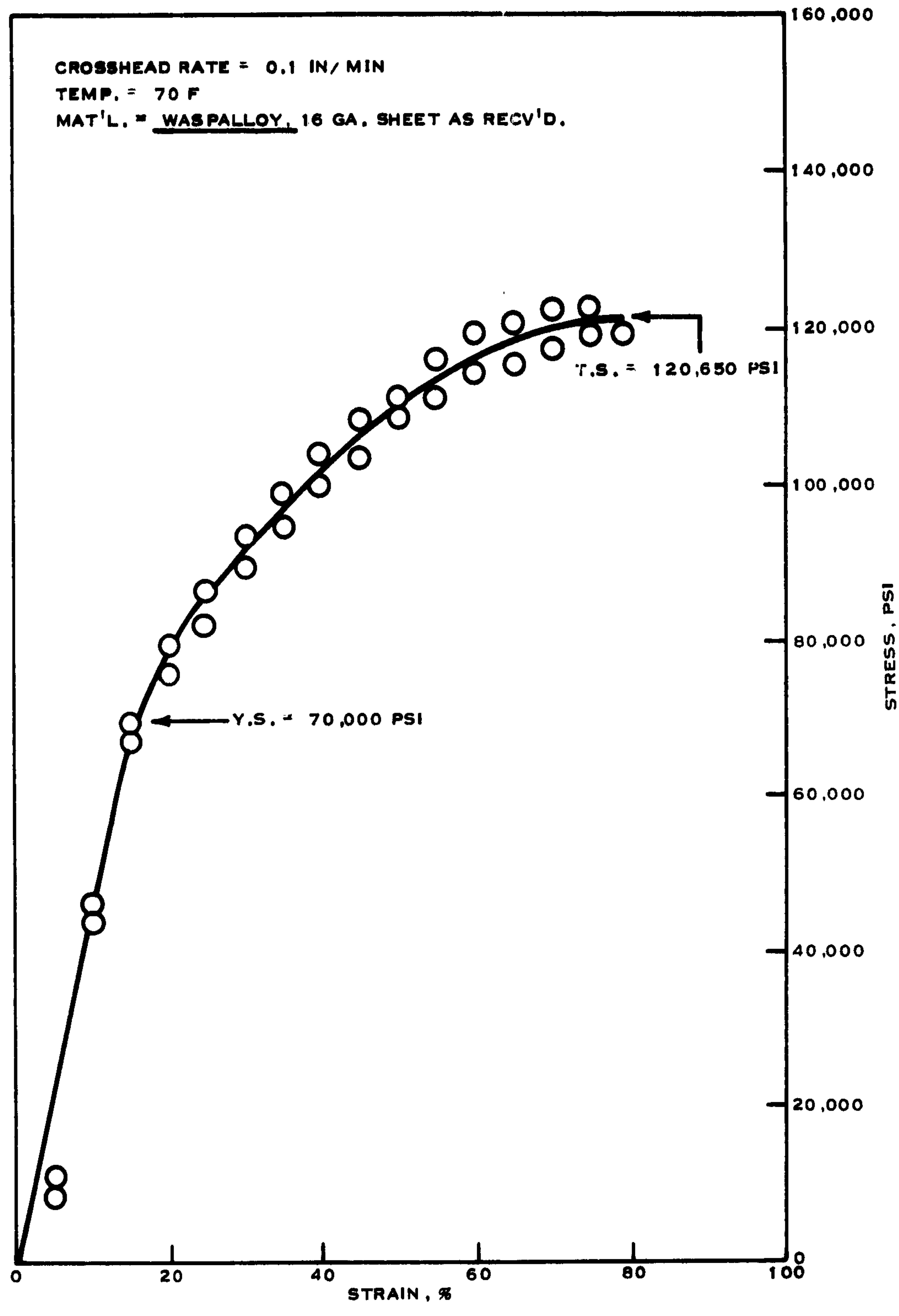


FIGURE 9
STRESS - STRAIN CURVE FOR UNEXPOSED WASPALLOY

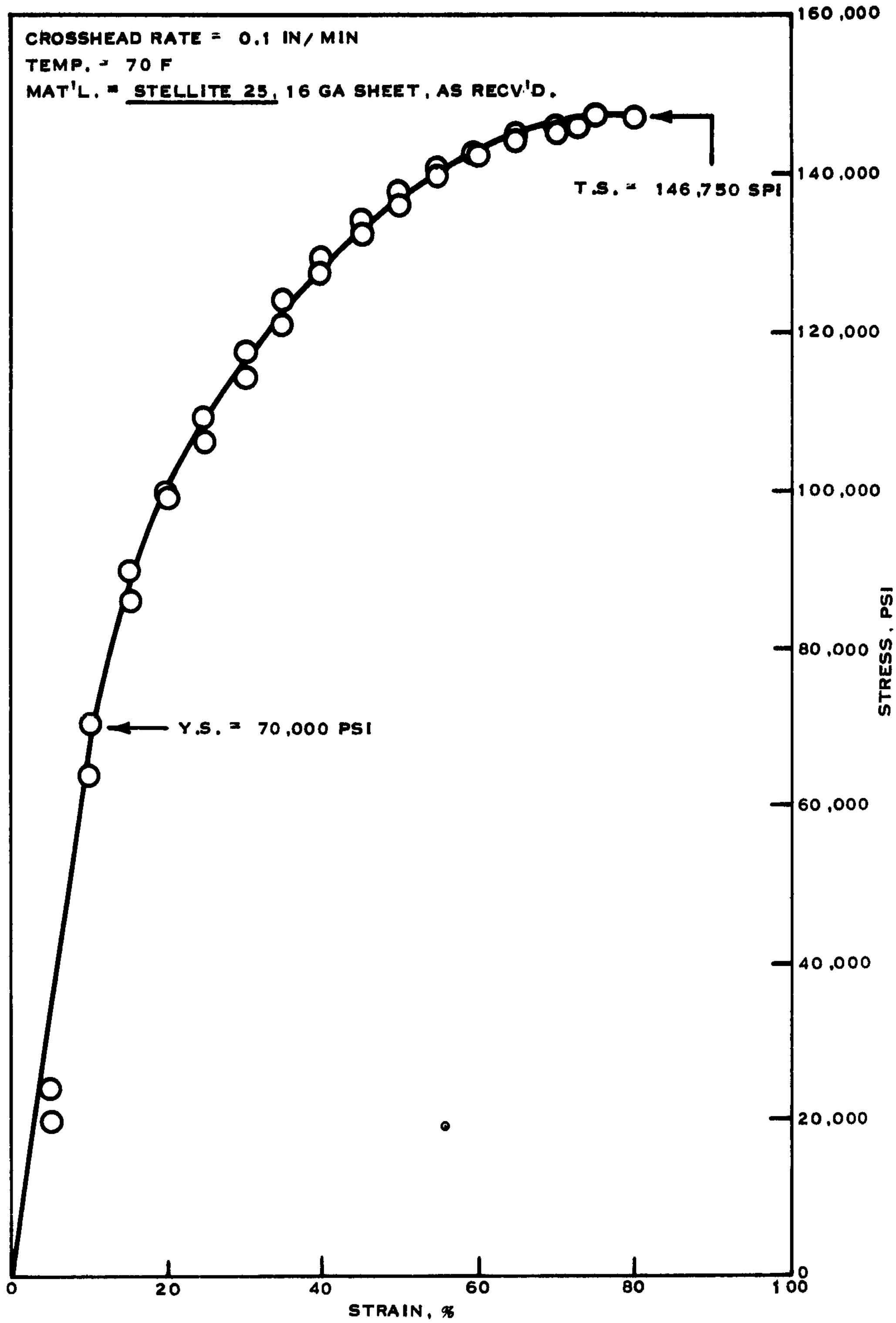


FIGURE 10
STRESS-STRAIN CURVE FOR UNEXPOSED STELLITE 25

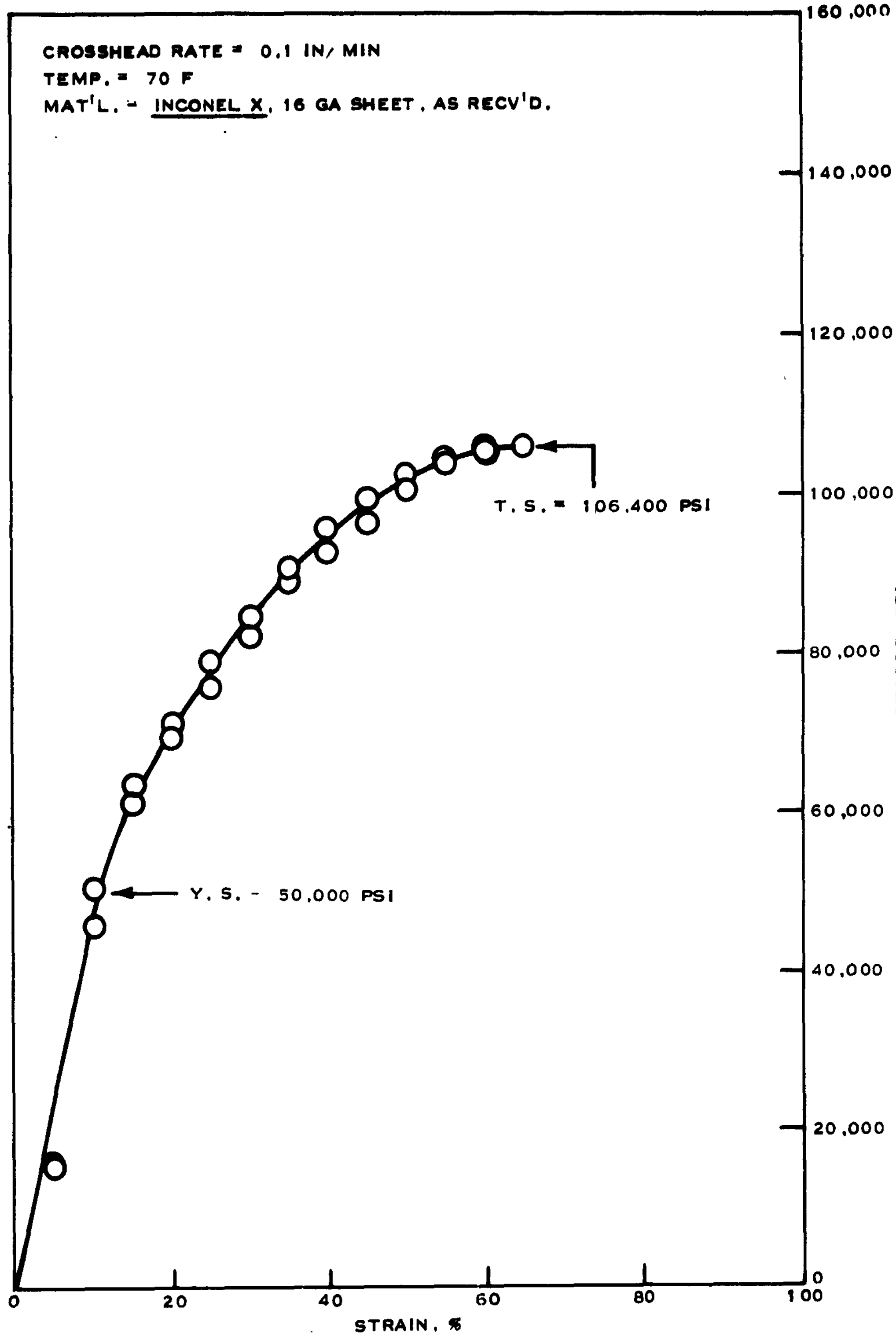


FIGURE 11
STRESS-STRAIN CURVE FOR UNEXPOSED INCONEL X

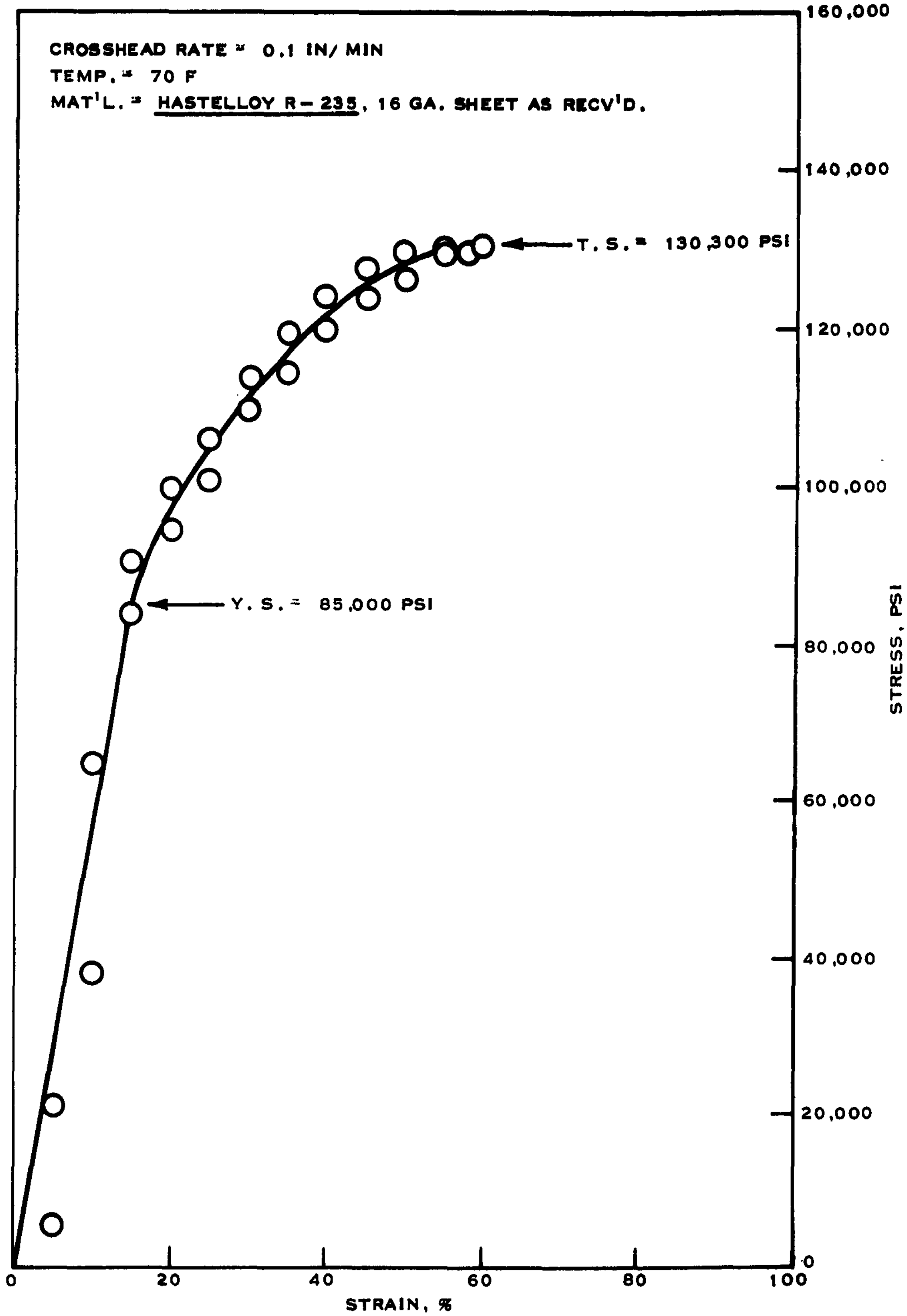


FIGURE 12
STRESS-STRAIN CURVE FOR UNEXPOSED HASTELLOY R-235

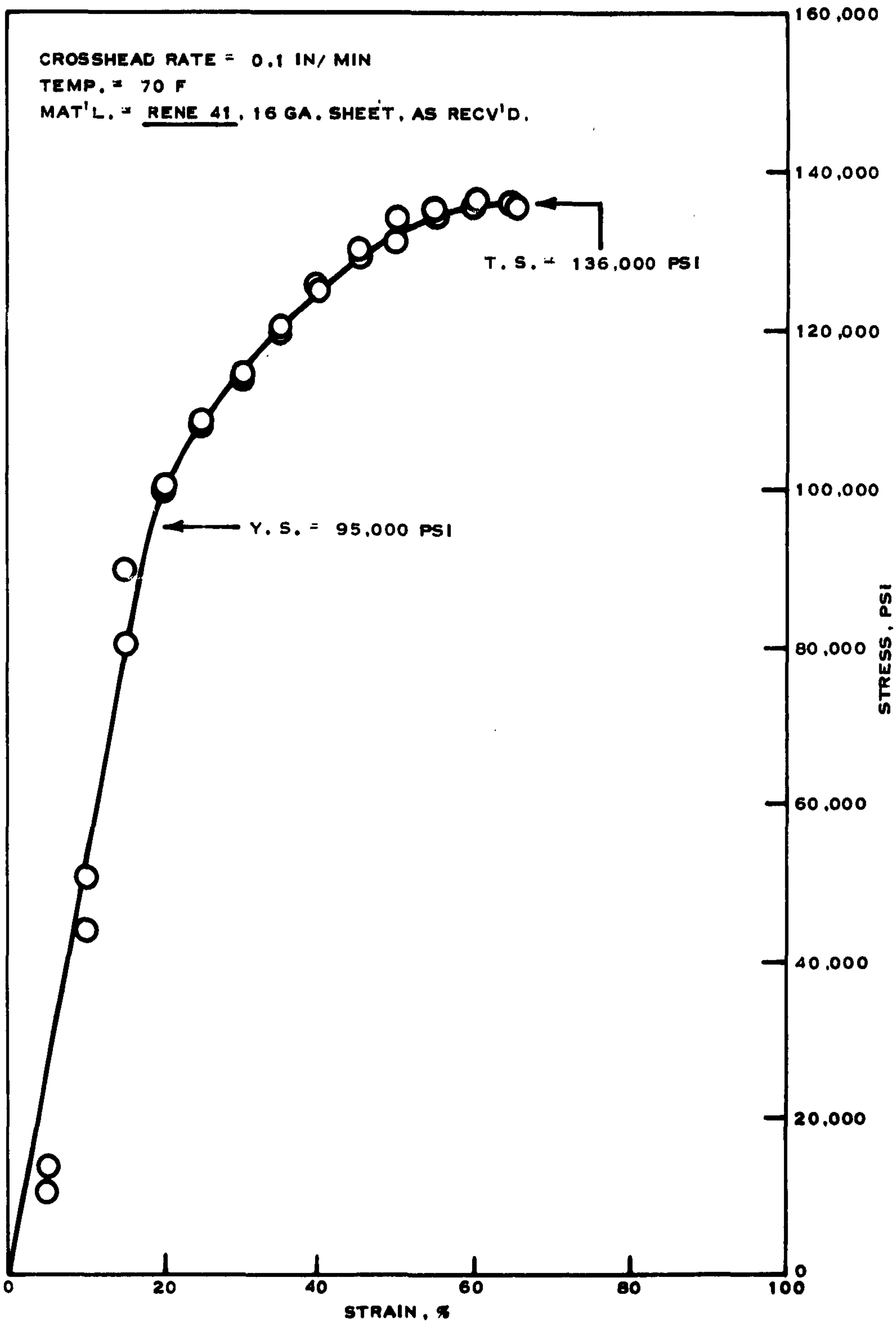


FIGURE 13
STRESS-STRAIN CURVE FOR UNEXPOSED RENE 41